Socio-economic assessement of farmers' vulnerability as water users subject to global change stressors in the hard rock area of southern India. The SHIVA ANR project

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Abstract: Demand for vulnerability assessments is growing in policy-making circles, to support the choice of appropriate measures and policies to reduce the vulnerability of water users and resources. Through the SHIVA ANR project, we are seeking a method to assess and map the vulnerability of farmers in southern India to both climate and socioeconomic changes, and secondly, to assess the costs and benefits associated with trends in farmers' vulnerability in the medium and long term. The project is focusing on southern India's hard rock area, as in this geological context, both surface and ground water resources are naturally limited. We are also focusing on farming populations as these are the main water users in the area and rely exclusively on groundwater. The area covers southern India's semi-arid zone, where the rainfall gradient ranges from 600 mm to 1100 mm. Vulnerability is expected to vary according to local climatic conditions but also the socioeconomic characteristics of farming households. The SHIVA research team has been divided into six thematic groups in order to address the different scientific issues: downscaling the regional climate scenario, farm area projections, vulnerability assessments and quantification, vulnerability mapping, hydrological modelling and upscaling, and vulnerability impact assessments. Our approach is multidisciplinary to cater for the numerous inherent themes, and integrated to cater for vulnerability as a dynamic and multidimensional concept. The project's first results after 10 months of research are presented below.

Keywords: Agriculture; GIS; Global change; hard rock aquifers; India; Multicriteria decision analysis; Vulnerability

Introduction

Although vulnerability is a multidimensional concept used in many disciplines with different interpretations (Alwang, Siegel et al. 2001; Brooks 2003; Füssel and Klein 2006), a consensual framework seems to have emerged to classify vulnerability approaches and clarify their origins (Füssel 2007). Within Füssel's framework, the main vulnerability approaches are described through a 2x2 matrix in two dimensions: sphere (or scale) and knowledge. Sphere can be internal (or local) or external (or regional), while the knowledge dimension is either socioeconomic or biophysical. In particular, this matrix is able to explain the fundamental differences between the two classic approaches to vulnerability - risk-hazard and political economy - and the IPCC approach to climate change vulnerability (Table 1).

Table 1 : Correspondence between the conceptualization of vulnerability according to several major approaches to vulnerability research (left-hand column), the vulnerability factors included (central columns), and their denotation according to Füssel's terminology - from Füssel (2007).

Approaches	Vulnerability factors				Denotation
	Internal Socioeconomic	Internal Biophysical	External Socioeconomic	External Biophysical	
Risk-hazard	-	x	-	-	Internal biophysical vulnerability
Political economy	x	-	?	-	Cross-scale socioeconomic vulnerability
Pressure-and-release	x	x	-	-	Internal integrated vulnerability
Integrated (e.g., IPCC)	x	x	x	x	Cross-scale integrated vulnerability
Resilience	x	x	?	?	Cross-scale (?) integrated vulnerability

Vulnerability to climate change is defined by the IPCC "*as the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the sensitivity of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects), adaptive capacity (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of exposure of the system to climatic hazards*" (McCarthy, Canziani et al. 2001). This approach to vulnerability to climate change differs from other main approaches because it is cross-scale and integrated and because it takes into account the "*long-term nature of the climate problem (by including adaptive capacity)*" and "*the heterogeneity and complexity of the hazard (by including a 'regional exposure factor')*" (Füssel 2007).

The SHIVA-ANR research project on farmers' vulnerability to global change is consistent with the IPCC vulnerability approach to climate change. However, global change includes an additional family of stressors, i.e. global economic changes (O'Brien and Leichenko 2000; O'Brien, Leichenko et al. 2004), since the internationalization of markets and economic activities has a significant impact on farming and food systems (Leichenko and O'Brien 2002). Global economic changes and climate change are already affecting farmers in water-stressed regions around the world and these impacts will increase significantly in the near future, especially in developing regions such as rural southern India, where economic changes are occurring rapidly and on a large scale (IPCC 2007). The SHIVA-ANR project aims to assess and map the vulnerability of southern Indian farmers to global change over two periods of time, in the medium term (2020-2040) to account for the faster dynamics of global economic changes, and in the long term (2045-2065) to account for the slower dynamics of climate change.

This four-year vulnerability study began in January 2009. This paper illustrates ongoing methodological developments and the first results achieved. Section 1 describes the project area with its three pilot sites where experiments are carried out. Section 2 describes the overall project methodologies and their relationship to the different research issues. Section 3 shows the first results achieved after 10 months of research. We conclude with a discussion of these initial results and how they will guide the work to come.

1. The study area

The project area was defined in accordance with three factors characterizing water-stressed areas in India (Figure 1). These are (i) the hard rock geological context: groundwater modelling of hard rocks is very specific, with groundwater recharge depending on a fissured layer that must be characterized (Dewandel, Lachassagne et al. 2006); (ii) the semi-arid climatic context, which has been defined according to the Indian ecoregion map, with annual rainfall ranging from 600 mm in the middle of the area to 1100 mm in the North-East and South-West; (iii) reliance on groundwater resources: perimeters irrigated with surface water are not covered in this study as they involve forms of collective and/or public management (water allocation, canal maintenance, etc.), whereas groundwater irrigation is exclusively private. In order to keep the study area as homogeneous as possible in terms of farming water use, we are focusing on groundwater use for irrigation.

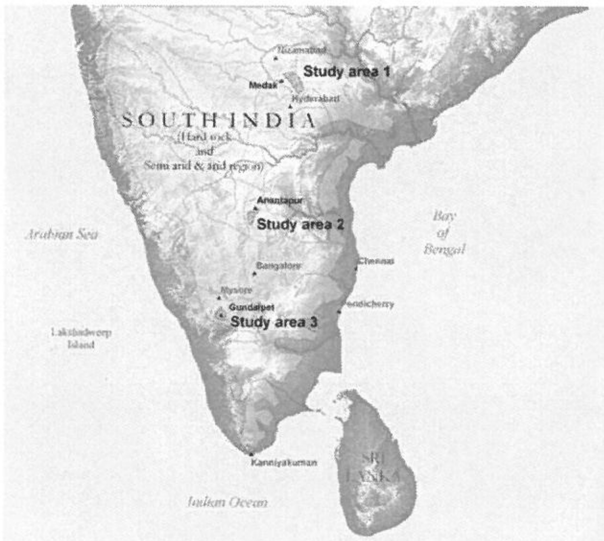

Figure 1: The SHIVA study area and the 3 pilot sites (http://www.shiva-anr.org).

Although the last factor seems restrictive at first glance, the main part of the study area relies on groundwater resources. For example, in Andhra Pradesh, 2/3 of the State is over 80% reliant on groundwater (Figure 2a). Figure 2b shows estimated over-abstraction of groundwater in Andhra Pradesh in 2005: the situation is already drastic in a large number of catchment basins (Dewandel, Gandolfi et al. 2007). Within the project area (Figure 1), three pilot sites were defined (noted as "Study are #" in Figure 1). These correspond to three catchment basins of around 700 km². They are representative of the climatic gradient of the project area. Two are located in Andhra Pradesh (Kudaliar and Padam Eru catchment basins) and the third near Mysore in Karnataka (South Gundal catchment basin). They are all situated in rural zones relying on agriculture, mainly cropping and small-scale livestock farming.

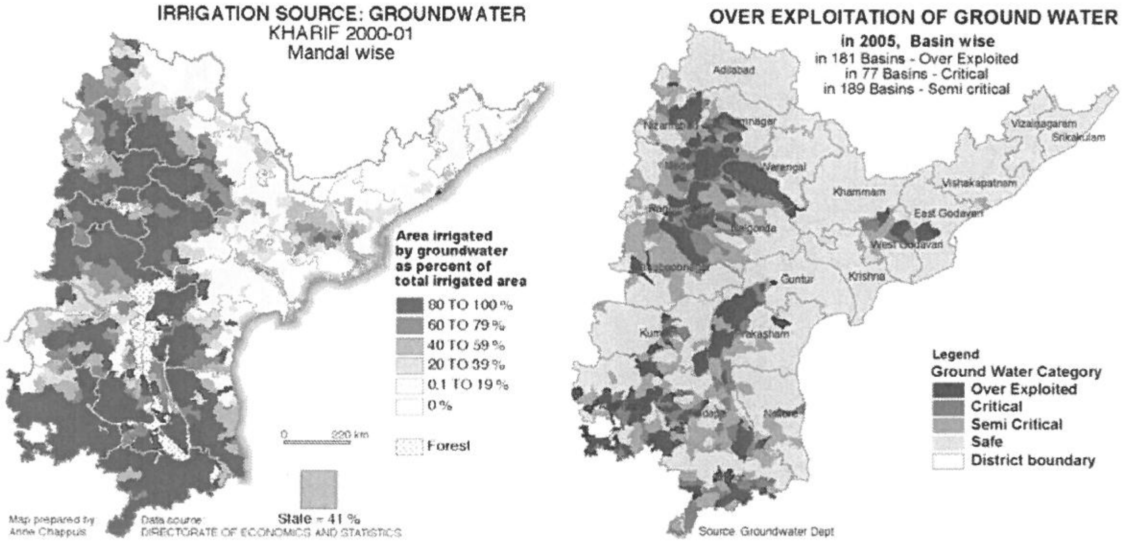

Figure 2: (a) Irrigation sources in AP in 2001; (b) Assessment of groundwater over-abstraction in AP in 2005 (Source: AP Department of Groundwater, 2005).

2. Methods

The overall project method combines socio-economic and biophysical approaches to analyze the interactions and feedback mechanisms between water systems and rural society (Figure 3).

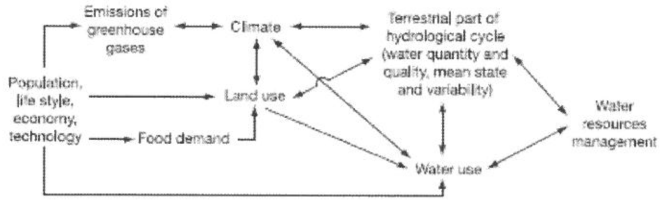

Figure 3: Impact of human activities on freshwater resources and management (from IPCC (2007)).

As shown in Figure 3, both climate change and global economic changes influence water resource supply and demand, which in turn influence global change. The scenario approach is widely used to predict either climate or socio-economic trends (Abildtrup, Audsley et al. 2006; Randall, Wood et al. 2007), by producing a picture of possible futures in a given area. To ensure overall consistency, the SHIVA project uses IPCC climate scenarios on the one hand (Randall, Wood et al. 2007), and the so-called SRES scenarios from the Special Report on Emission Scenarios (SRES) on the other (2007). Both types of scenario are global or regional, and have been downscaled to the appropriate level (pilot sites and project area). Both types of stressors are likely to affect water resources, and particularly groundwater. A SWAT model has been developed to characterize water table fluctuations in hard rock aquifers depending on monsoon variability and groundwater abstraction for irrigation (Dewandel et al. 2006, 2007). This spatialized model is able to handle daily climate variations and land use changes at a very local scale. The water table levels are simulated over the two periods of time defined for the project. The result is used as input in the calculation of future vulnerability among farmers.

Before estimating future vulnerability, the current state of farmers' vulnerability to climate and global economic hazards was assessed. The aim was to identify which farmers are more or less vulnerable, but also why. At the household level, sensitivity and exposure are almost the same (Smit and Wandel 2006; Eakin and Bojórquez-Tapia 2008). The first step is to analyze vulnerability into a number of indicators describing, first, sensitivity to global change, and secondly, farmers' adaptive capacity. The indicators are organized into a ranked matrix. Secondly, the indicators are weighted using the Analytic Hierarchy Process (AHP i.e. a multi-criteria decision analysis). Finally, a fuzzy approach is used to aggregate both sensitivity and adaptive capacity indexes and sort farmers' households into vulnerability classes. This vulnerability assessment method is compared to another one based on GIS (O'Brien and Leichenko 2000; O'Brien, Leichenko et al. 2004). By mapping rural vulnerability to both climate and global economic changes, we expect to obtain a more accurate idea of the predicted pictures of southern India's rural areas over the medium and long-term periods. With a GIS, different kinds of information (differentiated vulnerabilities, water resources, land cover, economic activities, population, etc.) can be superimposed at a predefined geographical scale (O'Brien, Leichenko et al. 2004; Metzger, Leemans et al. 2005; Meadows 2006; Procter, Comber et al. 2006). Finally, we will discuss possibilities for improving vulnerability mapping approaches to bring them closer to the household level results and thus reflect variability at a more local scale.

Rural vulnerability impacts are then evaluated through an economic (costs-benefit) and social assessment. A brief review of the literature shows that authors mainly focus either on the costs of climate change damage in a do-nothing scenario (Ruth, Coelho et al. 2007), or on the benefits and costs of climate change policies and measures (Watkiss, Downing et al. 2005), or on the costs of one type of damage (e.g. flooding or seawater rise) estimated locally for various scenarios (Elzen and Rotmans 1992). The SHIVA project aims to assess the impacts of global changes on the vulnerability of rural water users from a more holistic point of view, taking into account impacts on the rural economies but also on the social organization within the study area. Only then will we consider collective capacities for adaptation (policy measures or initiatives) in response to economic and social assessments.

3. Results

After defining the project area and the three pilot sites (Figure 1), methodologies for each issue were jointly discussed and partly established in order to avoid any problem with scale or input/output data. This is particularly important for an integrated study covering climate, economics, remote sensing and hydrology groups.

3.1. Downscaling the regional climate scenario

In order to investigate potential stress linked to global climate change on the local hydrological cycle of the three pilot catchment basins, statistical downscaling methods were applied to a set of IPCC SRES-A2 scenario projections taken from a pool of Global Climate Models (GCMs). Statistical Downscaling Methods (SDM) are generally validated by examining the quantiles, CDF/PDF of daily rainfall as well as wet spell length at local scale. One method recently developed by *Michelangeli et al.* (2009) based on CDF-transform (CDF-t) has the advantage of producing and handling local-scale CDFs. After validation of the historical statistical characteristics, the ensuing CDF-t is first calibrated to a 40-year period (1961-1999) and then applied to GCM A2 anomalies (2046-2065). The projected signal is reconstructed using the future large-scale seasonal cycle where historical biases have been removed. The results from CDF-t are then compared to downscaled GCM output using the Delta method from *Déqué* (2007). Both methods show an increase in precipitation amount from June to September, which is particularly pronounced for the southern Gundal basin during the second half of the monsoon season.

3.2. Hydrological modelling and upscaling

At the current stage in the project, the proposed approach for water cycle modelling is a lumped model made up of two reservoirs: (i) The upper reservoir simulates the water content in the soil according to rainfall and reference (or potential) evapotranspiration rates. Output from this reservoir is a breakdown of rainfall into real evapotranspiration and recharge, assuming that runoff is negligible most of the time; (ii) the lower reservoir simulates the water table in the aquifer according to recharge and pumping rates, and possible baseflow (maybe negligible).

The model can be run at daily time intervals. This modelling approach can take the impact of climate change on the recharge process into account (changes in evapotranspiration, rainfall amount and rainfall dynamics) and therefore its impact on water table elevation. The different types of land uses characterized by different water uses are defined through satellite images and field surveys: forest, grassland, drip-irrigated crops, paddy fields, vegetables, flowers, etc. Economic surveys provide cropping patterns (distribution in % of crops) and pumping rates at the village scale. Each land use type is simulated by a specific upper reservoir. All the upper reservoirs then percolate into a common groundwater reservoir at the village scale, according to surface-weighted recharge rates. This means that the water table is computed at the village scale, producing an estimate of the overall behaviour of the water table at this scale. The model is calibrated to historical piezometric time series supplied by State Groundwater Departments. The SWAT model can, *a priori*, handle all the above steps and conditions. It is widely used across the world and has a large set of references.

3.3. Assessment of farmers' current vulnerability

Farmers' vulnerability to global change in southern India is described in the ranked matrix shown in Figure 4.

Altogether, 15 local experts (government, NGOs, research areas) participated in the construction of the matrix and 4 of them participated in a test of the vulnerability assessment method in a small catchment basin (Gajwel, 80 km² inside study area 1 in Figure 1). These 4 experts were asked to make a pairwise comparison of indicator pairs using the AHP method. The resulting weightings were standardized to a 0-1 scale. In August 2009, a survey of 153 farmers stratified by operating area size was carried out in this catchment basin in order to quantify the matrix indicators. The indicators were also standardized to the same scale, ranging from 0 (less sensitive / more adaptable) to 1 (more sensitive / less adaptable). Weightings and indicator values were aggregated according to Eq. 1, Eq. 1 using the concept of distance to an anti-ideal point (here, vulnerability = 1).

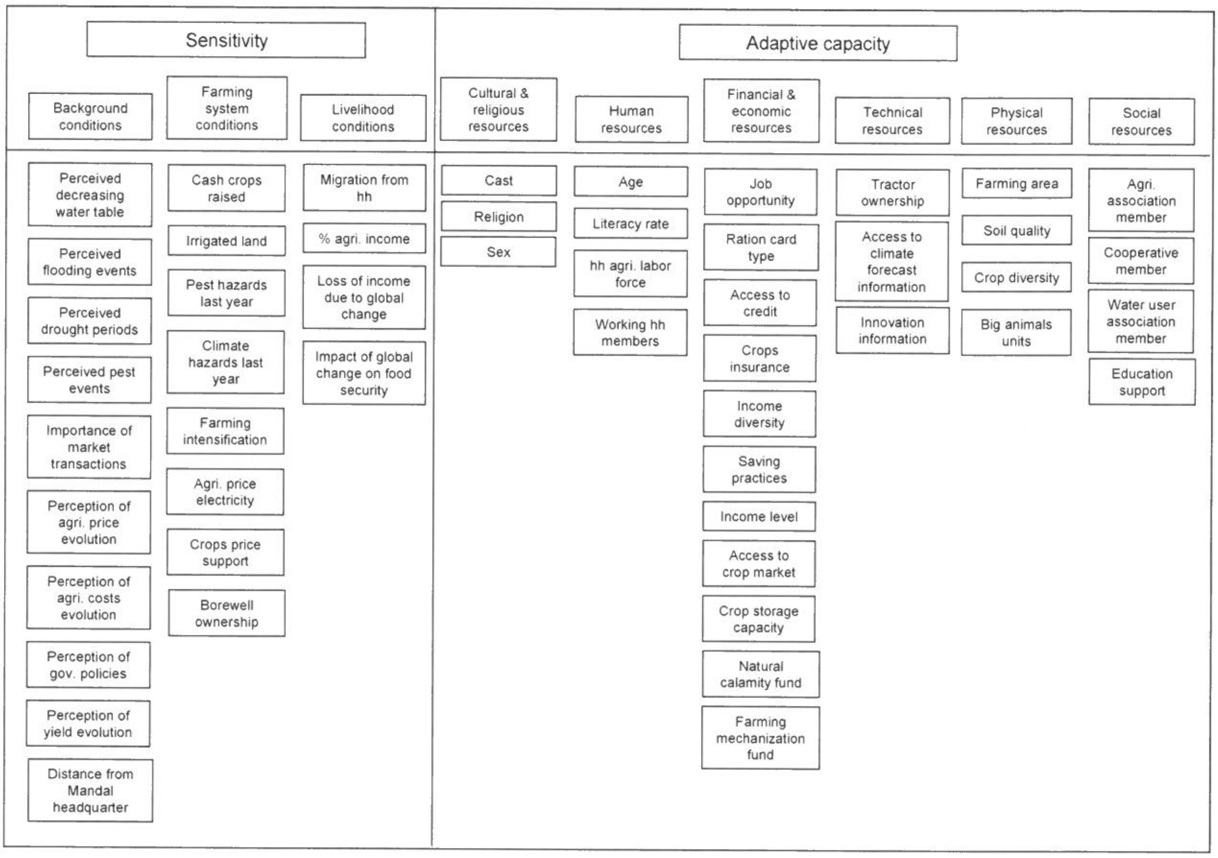

Figure 4: Ranked matrix of indicators used to calculate sensitivity and adaptive capacity indexes.

$$d_i = \left[\sum_j^J w_j^p (1 - x_{ij})^p \right]^{1/p} \tag{1}$$

where d_i is the distance to the anti-ideal point of the i^{th} farmer, w_j is the weighting of the j^{th} indicator, x_{ij} is the standardized value of the j^{th} indicators of the i^{th} farmer and p is a constant metric distance parameter setting a mode of compensation when a variation of the distance for one indicator is applied. Results are presented here with $p=1$, meaning that a reduction in the distance for one indicator can be compensated by an equivalent increase in the distance for another indicator.

As it was extremely difficult for the experts to decide whether adaptive capacity or sensitivity contributes more to farmers' vulnerability, we applied fuzzy logic to the two indexes. Contrary to probability approaches, fuzzy logic is linked to uncertainty. The fuzzification of the 2 index values uses the Low, Medium, High classification. FisPro© software (developed by INRA-CEMAGREF, France) was used to combine the fuzzified sensitivity and adaptive capacity classes into 5 fuzzified classes of vulnerability (Very High, High, Medium, Low, Very Low). A vulnerability score is obtained per farmer with a degree of membership of each vulnerability class. Results are presented in Figure 5, showing a wide variability in results between experts. When equal weightings are attributed to indicators, the vulnerability score seems underestimated. Another result is also the small range of vulnerability scores within villages. This is probably due to the lesser degree of farming heterogeneity within village units than among villages.

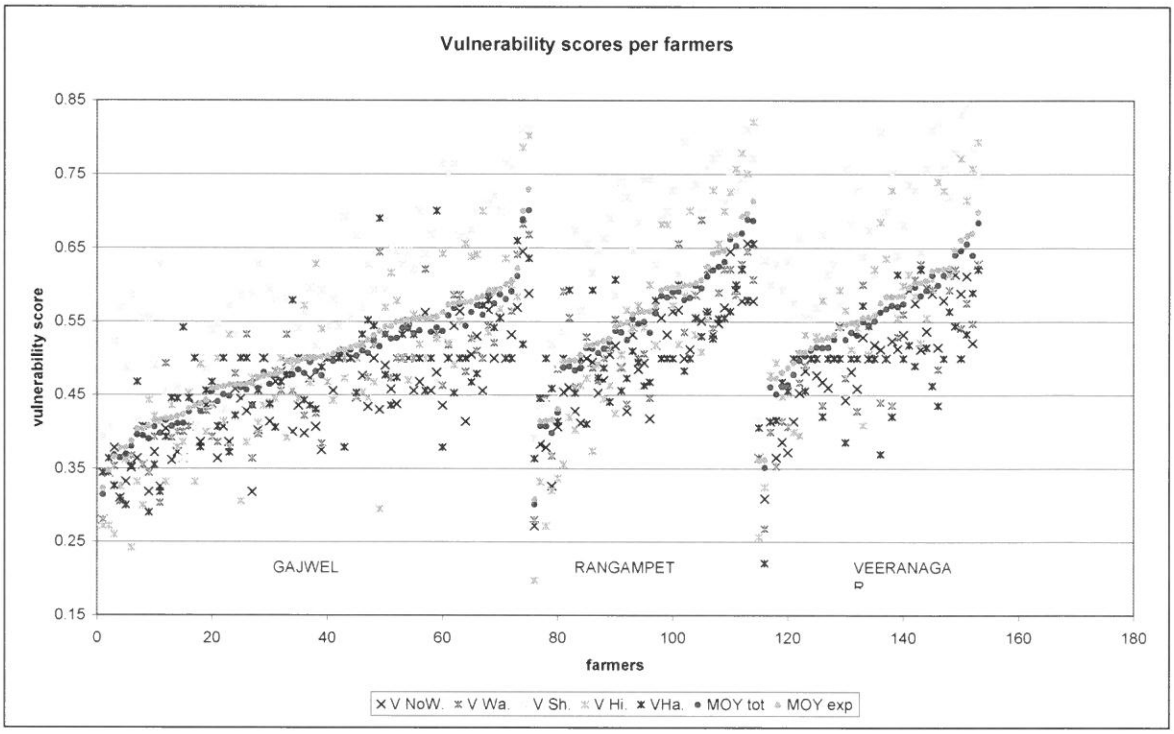

Figure 5: Farmers' vulnerability scores presented per village surveyed and according to different weighting profiles: equal weighting for all indicators (NoW.), 4 expert profiles (VWa, VSh, VHi, VHa), mean of all 5 profiles (MOY tot), mean of expert profiles (MOY exp).

Finally, a major advantage of the method is that it is able to describe the origins of vulnerability. Figure 6 shows how the standardized values of the matrix indicators ultimately contribute to the vulnerability score, on average and per class of vulnerability. Thus, regarding sensitivity indicators, highly vulnerable farmers are particularly sensitive to output price fluctuations, have more irrigated lands, suffered from climate hazards in the previous season, own borehole wells, receive price support, and their farming income makes up a high proportion of their total income. Regarding their adaptive capacity, they have a lower literacy rate, lower income diversity and their total income is smaller, they save less money, they do not use weather forecasts and have poor quality soils. Figure 6 shows that the most important indicators of sensitivity are the number of borehole wells owned, the area irrigated, crop price support and recent experience of a climate hazard. Characteristics that make farmers more adaptable are mainly the amount of savings and total income, their access to information on weather and innovation and the soil quality of their land.

This analysis can also be carried out per village or per category of farmers, etc., to target a specific place or a specific population. It makes this approach particularly useful to support agricultural or water management policy decisions.

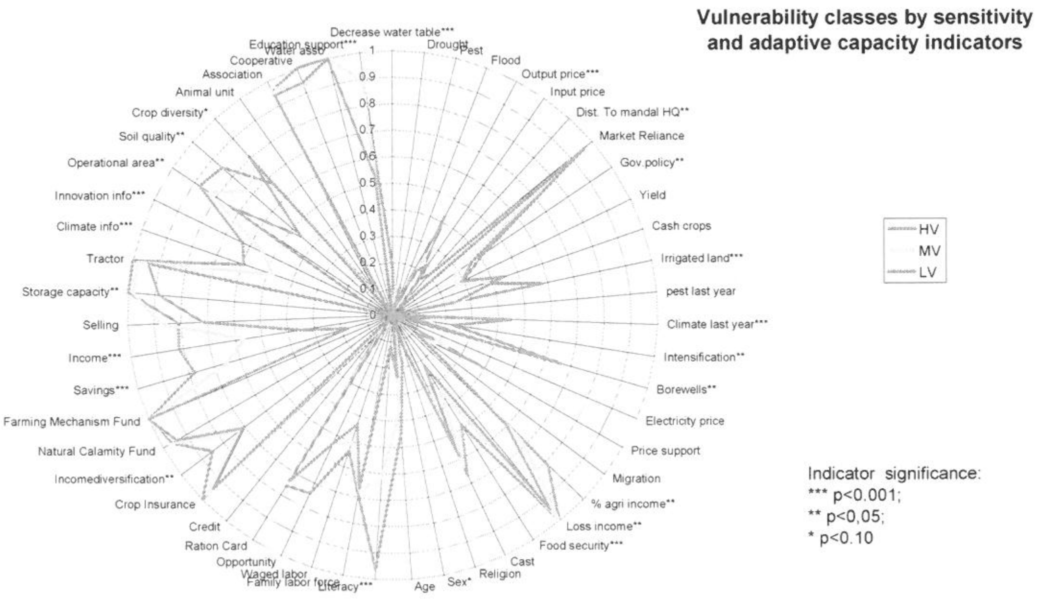

Figure 6: Vulnerability classes by sensitivity and adaptive capacity indicators (given for experts' average scores).

Conclusion

In its first year, the SHIVA-ANR project focused on setting out and sharing methodological issues, which is crucial for this type of multidisciplinary work. Climate, socioeconomic and hydrological methodologies were established and first outputs are expected as from the end of 2010. After the test in small Gajwel catchment basin, the vulnerability surveys will be applied a set of 3000 farmers covering the areas of the 3 pilot sites. Thus, current vulnerability of farmers will be assessed and discussed. This approach will be compared to a GIS based method which could be used as an upscaling tool for vulnerability assessment. Coming tasks to achieve are future vulnerability impact assessment issues and guidelines for policy makers and groundwater managers for the economic contribution and finalization of climate downscaling scenarios and hydrogeological modelling for the biophysical part of the project.

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